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Development of an investment decision tool for biogas production from agricultural waste

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ABSTRACT

Anaerobic digestion is a very promising solution for the treatment of agricultural waste, preventing pollution and leading to efficient energy production. Since this technology is available to each farmer in a different way depending on the location and the scattering of the primary sources, it is essential to clarify the best conditions adapted to local situations to treat the targeted residues and make this information accessible to farmers. In particular the possibility of codigestion seems to be very attractive for farmers who will be able to treat their own waste together with other organic substrates. Their profit in this case is double since they treat properly their own residues, taking advantage of the selling of heat and electricity as well as the utilisation of a stabilised biofertiliser. The aim of this paper is to present an investment decision kit for economic evaluation of biogas plant projects based on agricultural feedstocks.

Contents

1. Introduction

Anaerobic digestion is a multi-step biological process during which the organic carbon is converted to its most oxidized (CO_2) and most reduced (CH_4) state without the presence of air [1]. The product of the process is biogas which is a mixture of methane and

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Table 1
Typical composition of biogas.

Methane, CH_4	55–75%
Carbon dioxide, CO_2	25–45%
Carbon monoxide, CO	0–0.3%
Nitrogen, N_2	1–5%
Hydrogen, H_2	0–3%
Hydrogen sulphide, H_2S	0.1–0.5%
Oxygen, O_2	Traces %

carbon dioxide, as well as trace gases such as hydrogen sulphide and hydrogen. Table 1 presents the typical composition of biogas.

The biogas production process is complex and sensitive since several groups of microorganisms are involved. The important processes in anaerobic digestion are hydrolysis, fermentation, acetogenesis, and methanogenesis, where hydrolysis is subject to the fermentation process, while acetogenesis and methanogenesis are linked. The hydrolysis step is an extra-cellular process where the hydrolytic and fermentative bacteria excrete enzymes to catalyse hydrolysis of complex organic materials into smaller units. The hydrolysed substrates are then utilised by fermentative bacteria. Fermentation products such as acetate, hydrogen and carbon dioxide can directly be used by methanogenic microorganisms producing methane and carbon dioxide, while other more reduced products such as alcohols and higher volatile fatty acids are further oxidized by acetogenic bacteria in syntrophic with the methanogens [2].

2. Digester technology/geometry based on substrates/feedstock and estimation of key feedstock parameters

The feedstock to be utilised in a biogas-to-energy establishment/plant is considered to constitute of a mixture of biomass input streams, mainly:

- organic wastes (pig manure, sludge from wastewater treatment plants, etc.) [3,4].
- energy crops (sweet sorghum, miscanthus, rape, sunflower, etc.) [5].
- conventional crops (maize, wheat, sugar beet, etc.) [6,7].
- other organic feedstocks (e.g. glycerol, etc.) [8].

Usually, different input streams are forwarded to a biogas plant according to feedstock availability, activities in the region of application, economic considerations, etc. Hence, a biogas plant operates not on a specified input stream but rather on a combination of different biomass input streams, with variable composition, which constitute the "feedstock mixture" [9,10].

The four basic components/modules of a generic anaerobic digestion plant include:

1. A pretreatment module, intended to prepare the diverse feedstocks and homogenise them in a single-feed stream with characteristics within a specified range (in terms of dry matter content, temperature, pH, inorganic matter – especially N-content as well as C:N ratio – and feedstock size) prior to entering the digester.
2. The digester itself, which is the key component of any anaerobic process operating:
   - in the mesophilic (30–45 °C) or the thermophilic range (45–54 °C).
   - with internal (agitators) or external (circulation of the produced biogas) agitation.
   - in the dry (with a total solids, TS, content >20%) or the wet region.

depending on the characteristics of the feedstock mixture [11].

Anaerobic digestion variants employed for processing energy crops with higher N-content, usually work in the mesophilic range due to increased evolution of NH_3 in higher temperatures. NH_3 is acting as an inhibitor of the methanogenesis process.

The digester is usually deployed in the so-called primary digester (where the majority of anaerobic processes occur and where biogas, by ≈90%, is mainly produced) and the secondary digester which also serves as gas storage tank.

3. The gas treatment line, which constitutes of:
   - biogas cleaning devices (usually a spray scrubber), the basic aim of which is to deliver biogas with low H_2S-content to the internal combustion engines (ICE).
   - the devices for the utilisation of the energy content of the produced biogas, usually modified ICEs operated in the cogeneration mode.
   - gas flares to be used as emergency devices for the incineration of excess biogas in case ICEs are off-grid or unavailable for some reason (i.e. scheduled maintenance or equipment failure).
4. The solids-treatment line, to treat the digested biomass which constitutes of:
   - A decanter separator which separates the fibre fraction (with a TS content of ≈35%) from the liquid fraction (with a TS content of ≈2.5%).
   - The liquid fraction treatment, which usually constitutes of an evaporator (which also utilises the thermal energy/waste heat from the ICEs) or an MBR (membrane reactor). In some cases, the liquid fraction can be directly utilised for irrigation, while in others it is necessary to treat the rich, in inorganic components (mainly N, P, K) effluents prior to end disposal, depending on land availability.

A simplified flow diagram of a generic anaerobic digestion plant is shown in Fig. 1

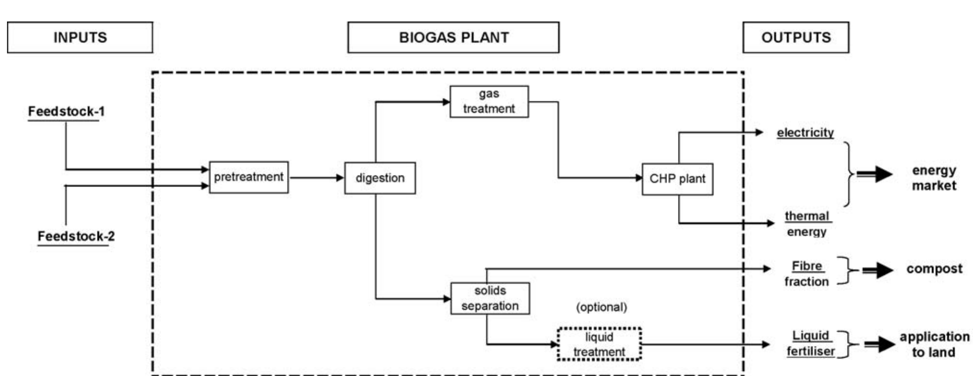


Fig. 1. Simplified flow diagram of a generic anaerobic digestion plant based of organic feedstocks.

3. Combination of reactor technology with feedstocks-reactor configurations

Anaerobic digesters are separated according to their operation type (batch, semi-continuous or continuous operations) [2,12].

It is particularly noted that anaerobic digestion technology has recently been developed to suit the conversion of energy crops. When it comes to plant size, anaerobic digestion of organic wastes and energy crops can be divided in:

- Horizontal digesters (volume 50–150 m^3) suitable for the smallest size plants and well-suited for treatment of cow and poultry manure as well as feedstocks with increased TS (energy crops) due to the very good mixing conditions.
- Upright standard agricultural digesters (volume 500–1500 m^3, with height 5–6 m and diameter 10–20 m). The tanks are equipped with an internal heating system and external motor(s) for mixing, while in the top of the tank a double-membrane, gas-holder roof is fitted. This device has a treatment capacity of up to 10,000 m^3/year and the hydraulic retention time is between ≈3 and 80 days depending on the input substrate.
- Upright large digester (volume 1000–5000 m^3, with height 15–20 m and diameter 10–18 m). In these devices the input material is pre-heated and mixing is performed by centrally located, continuously operating, roof-mounted mixer. The advantages of preheating and continuous mixing achieve much lower hydraulic retention times (20–30 days). This type of digester is used for the treatment of up to 90,000 m^3/year per single unit. Larger centralised plants (i.e. in Denmark or Germany) have often two or more such digesters.

Choice of reactor type is determined by waste characteristics, especially particulate solid contents or total solids (TS). High TS feedstocks and slurry waste are mainly treated in Continuous flow Stirred Tank Reactors (CSTRs), while soluble organic wastes are treated using high-rate biofilm systems such as anaerobic filters, fluidised bed reactors and upflow anaerobic sludge blanket (UASB) reactors [13].

Some of the substrates examined, are presented in Table 2. As seen, the high TS of the substrate in the anaerobic digester necessitates the choice of CSTR configuration for the majority of the feedstocks considered. CSTR is a quite reliable technology which is widely used in various countries like for example in Denmark [14].

Besides these standard configurations, recent advances focus on the improvement of reactor volume by utilising the dry fermentation (a CSTR variant) for the digestion of energy crops. Dry anaerobic digestion takes place at dry matter content in the primary digester in the range 20–45%. It has been mostly limited to the digestion of the organic fraction derived from municipal solid wastes (MSW), as well as mixtures of source separated organics (kitchen waste or biowaste), the organic fraction of residual wastes and the organic fraction of mixed MSW. These feedstocks are being successfully treated by means of anaerobic fermentation, with more than 50 "dry" anaerobic digestion plants treating organics derived from MSW. Several anaerobic digestion plans have been developed over the years and have been presented in various works [16,17]. Some of them are: VALORGA [18], OWS-DRANCO process [19,20], BTA [21].

The application of dry fermentation to energy crops has been limited, since most of the anaerobic digestion plants are designed to treat liquid manure with a smaller proportion of maize being added. However, by increasing the energy crops proportion to the feed mix, the following advantages can be obtained:

(1) anaerobic digestion projects can be set up independently of the availability of liquid manure or the addition of water.
(2) volumes of the digesters are minimised.
(3) thermophilic operation (50–55 °C) is favoured, due to the lower thermal energy needed to heat up small volumes and concentrated (higher density) feedstocks.

Table 2
Substrates and recommended digester configuration [15].

Substrate (organic feedstock)	Process of biogas production	Reactor configuration	List of equipment needed
Pig manure	Mono/codigestion	CSTR[a] or plug-flow	Standard structure[b] + biogas desulphurization
Rape	Mono/codigestion	CSTR or plug-flow	Standard structure
Sunflower (WCS)	Codigestion	CSTR or plug-flow	Standard structure
Orange	Codigestion	CSTR or plug-flow	Standard structure
Pear	Codigestion	CSTR or plug-flow	Standard structure
Apple	Codigestion	CSTR or plug-flow	Standard structure
Sweet sorghum	Mono/codigestion	CSTR or plug-flow	Standard structure
Lucern	Mono/codigestion	CSTR or plug-flow	Standard structure
Glycerol	Codigestion	CSTR or plug-flow	Standard structure
Peas (WCS)	Codigestion	CSTR or plug-flow	Standard structure
Barley silage	Mono/codigestion	CSTR or plug-flow	Standard structure
Spring Wheat Grain	Mono/codigestion	CSTR or plug-flow	Standard structure
Autumn Wheat Grain	Mono/codigestion	CSTR or plug-flow	Standard structure
Hemp	Only with hydrolytic pretreatment	CSTR or plug-flow	Standard structure + hydrolytic pretreatment
Miscanthus	Codigestion	CSTR or plug-flow	Standard structure
Maize stalks	Codigestion	CSTR or plug-flow	Standard structure
Sugar Beet	Codigestion	CSTR or plug-flow	Standard structure
Barley grain	Codigestion	CSTR or plug-flow	Standard structure
Grass, meadow	Mono/codigestion	CSTR or plug-flow	Standard structure
Maize	Mono/codigestion	CSTR or plug-flow	Standard structure
Maize grain	Codigestion	CSTR or plug-flow	Standard structure
Distillery waste	Codigestion	CSTR or plug-flow	Standard structure + biogas desulphurization
Bakery waste	Codigestion	CSTR or plug-flow	Standard structure
Starch waste	Codigestion	CSTR or plug-flow	Standard structure
Manure	Mono/codigestion	CSTR or plug-flow	Standard structure
Straw	Codigestion	CSTR or plug-flow	Standard structure
Willow	Only with hydrolytic pretreatment	CSTR or plug-flow	Standard structure + hydrolytic pretreatment
WWTP Sludge	Mono/codigestion	CSTR or plug-flow	Standard structure

[a] CSTR, continuous stirred tank reactor.
[b] Standard structure includes: biomass storage tanks, homogenisation and feeding system, digestion tank and mixing system, gas cleaning, cogeneration unit and digestate tank.

Table 3
Substrate/feedstock characteristics and CH_4 production in the 3-feedstocks example.

Substrate-feedstock type	Input (tons/year)	Total Solids (TS) (g TS/kg feedstock)	TS/VS (%)	Volatile Solids (VS) (g VS/kg feedstock)	CH_4 yield (Nm^3 CH_4/ton VS)	CH_4 production (Nm^3 CH_4/year)
Fresh pig manure (sows)	20,000	56.00	80.00	44.80	362.50	324,800
Wheat straw (chopped)	10,000	850.00	94.00	799.00	334.89	2,675,800
Glycerol	15,000	800.00	95.00	760.00	631.58	7,200,000
Total	**45,000**					**10,200,600**

Table 4
Calculation of digested biomass (example for the three feedstocks considered).

Substrate-Feedstock type	Input (tons/year)	TS (tons/year)	VS (tons/year)	Decomposition rate (%)	VS out (tons/year)	Digested biomass (tons/year)
Fresh pig manure (sows)	20,000	1120	896	50	448	19,552
Wheat Straw (chopped)	10,000	8500	7990	77	1838	3848
Glycerol	15,000	12,000	11,400	95	570	4170
Total	**45,000**	**21,620**	**20,286**		**2856**	**27,570**

Table 5
Produced biogas in the 3-feedstocks example.

Input feedstock	(Nm^3 CH_4/ton VS)	m^3 CH_4/year	Nm^3 biogas/year[a]
Fresh pig manure (sows)	362.50	324,800	523.871
Wheat straw (chopped)	334.89	2,675,800	4.315.806
Glycerol	631.58	7,200,000	11.612.903
Mean/Total CH_4 production	**502.84**	**10,200,600**	**16.452.581**

[a] CH_4 content in biogas is ≈62%.

(4) less intensive mixing is needed inside the digester, which leads to the reduction of parasitic consumption of generated electricity (thus, an increase to the power exported to the grid).
(5) infrastructure and logistic costs for the provision of the feedstock to the plant is reduced due to the increased bulk density of the energy crops (compared to the liquid manure).
(6) lower liquid fertiliser amount for subsequent treatment.

A simple schematic of a dry fermentation application, which utilises the organic waste systems (OWS) DRANCO process is presented in Fig. 2.

4. Estimation of biogas production and derivation of mass and energy balances

In the current study, an investment decision tool (IDT) has been developed in order to evaluate the biogas production for various feedstocks. Possible feedstocks have been already presented in Table 2. As a first step for developing the IDT, an example for an anaerobic digestion plant where 3-feedstocks are utilised is

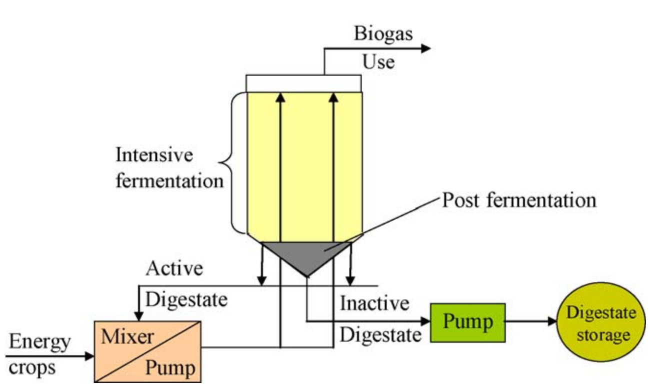


Fig. 2. Basic flow diagram of the DRANCO dry fermentation, anaerobic digestion process applicable for energy crops.

analysed. Based on the example results, some key rules will be derived to be used as guidelines for estimating the performance of larger plants, where more feedstocks could be simultaneously utilised (in the, so-called, codigestion mode).

The basic characteristics of three such specific substrates/ feedstocks and the relevant, calculations leading to the estimation of methane (CH_4) production are summarised in Table 3.

It should be noted that the batch tests only show the potential (maximum) CH_4 production for a certain substrate/crop. In a continuous anaerobic digestion process, these results may differ significantly. Hence, it is expected that in continuous processes the actual yields are lower due to lower degradation of organic matter and to existence of trace elements.

The CH_4 production is dependent on the content of the TS, the ratio of total solids to volatile solids (TS/VS) and the specific CH_4 yield, measured as Nm^3CH_4/ton VS.

It can be noted that the above estimation calculates the maximum methane (CH_4) production and that in continuous processes the above figures are expected to be lower.

Considering further the respective decomposition rates for the TS and VS of the given feedstocks in the primary digester, the digested biomass leaving the digester is calculated in Table 4.

In the following, the produced biogas is sent to the gas treatment line, where it is purified (H_2S and other sulphur containing gases to acceptable levels, i.e. to ≈50–60 ppm) and then its energy content is utilised in internal combustion engines (ICEs). The biogas energy utilisation scheme main figures are depicted from Tables 5 and 6.

Table 6
Biogas production data in the 3-feedstocks example.

Biogas production	45,076	Nm^3 biogas/day
Biogas production	1878.15	Nm^3 biogas/hour
Biogas production[a]	18,627.61	tons/year
Biogas production per ton of biomass	365.61	Nm^3/ton
CH_4 production per ton of biomass	226.68	Nm^3/ton

[a] Biogas density is ≈1.132 kg/Nm^3.

Table 7
Internal combustion engines (ICEs) performance key figures for the 3-feedstocks example.

Key figures	Values	Units
CH_4 for use in the CHP module	10,200,600	Nm^3 CH_4/year
CHP plant availability	85.00%	%
Energy input	13,617	kW
Electrical efficiency	39.10%	Nominal
CHP installed power	5324	kW
Electricity generation	39,645,040	kWh_e/year
Own consumption	15.00%	%
Net electricity	33,698,284	kWh_e/year
Diverse losses	6.00%	%
Exports to grid	31,676,387	kWh_e/year
Heat losses	23.50%	%
Thermal power	5093	kW
Heat generation	37,921,343	kWh_{th}/year

Table 8
Decanter separator performance and key figures for the 3-feedstocks example.

Parameters	Values
% Of digested biomass to separator	100%
Separated digestate (tons/year)	25,924
Operational hours[a]	2102
Separator capacity (tons/h)	12.3
Dry matter (DM) in fibre fraction	35.0%
Dry matter (DM) in liquid fraction	2.5%
Nitrogen (N)in fibre fraction	20%
Phosphorus (P) in fibre fraction	80%
Potassium (K) in fibre fraction	10%

[a] The optimum operation period for the decanter is approx. for 24–25% availability.

Based on the above derived data, the key figures for the ICEs performance data are depicted from Table 7.

The digested biomass is guided to a decanter separator, leaving a solids stream with dry matter (DM)-content of ≈35% and a liquid fraction with a DM-content of ≈2.5%, as shown in Tables 8 and 9.

5. Economic evaluation of the actual biogas plant (ABP)

In this section, the techno-economic viability of the project under consideration, i.e. the implementation and operation of an anaerobic digestion plant based on the three organic feedstocks discussed above is examined. More specifically an estimation of plant economics for the examined biogas plant is concentrating on updated figures of plant performance and on expected total plant costs (TPC) and the CAPEX (the total project cost including development and contingency). Furthermore, an estimation of the separate cost items that comprise the total operating costs (TOCs), including the feedstock costs, is presented. Finally, based on the findings from this analysis, the viability of the project is discussed.

An investor, energy policy analyst, or developer may use a variety of figures of merit to evaluate the financial attractiveness of any project. Although the choice often depends on the purpose of the analysis, in what concerns the viability of biogas-to-energy projects, figures like the project's capital cost, the projected energy (electricity and thermal energy) output and annual revenues from sales of the fibre fraction (compost) will be considered, while the expenses (operating costs) usually comprise of net operating costs (including feedstock costs, in particular energy crops) and financing costs. A pro-forma earnings statement, debt redemption schedule and statement of after-tax cash flows will typically also be prepared. Annual after-tax cash flows are then compared to initial equity investment, to determine available return. For another perspective, before-tax, no-debt cash flows may also be calculated and compared to the project's total cost. The primary figures of merit are:

Table 9
Mass balance in the decanter separator streams for the 3-feedstocks example.

	Units	Fibre fraction[a]	Liquid fraction	**Total**
Distribution	%	55.48	44.52	**100.00**
Output (mass flow)	tons/year	14,328	11,498	**25,827**
Dry matter (DM) content	tons/year	5015	287	**5302**

[a] After maturation (70% of remaining water and 10% of DM is lost) a fraction with ≈37% remains (7560 tons/year) which can be sold as compost (Grade V) to the market.

Net present value: Net present value (NPV) is the sum of all years' discounted after-tax cash flows. The NPV method is a valuable indicator, because it recognizes the time value of money. Projects whose returns show positive NPVs are attractive. The higher the NPV, the more profitable is the project.

The NPV is defined as:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} \quad (1)$$

where NPV is the net present value of the project (€), CF_t is the cash flow of the investment in time period t (€), r is the discount rate (%), t is the time period from 0 to n (years).

The advantage of the NPV is its additiviness and the respect of the time value of the money. This simply means that the NPVs of different projects can be summed up and the total benefits from the implementation of more investments can be quantified.

The disadvantages of the NPV is the difficulty to determine the discount rate and that the NPV, being an absolute variable, does not express the accurate rate of profitability.

Internal rate of return: Internal rate of return (IRR) is defined as the discount rate at which the after-tax NPV is zero, which means that the present value of the investment funds equals the net present revenues from operation. The calculated IRR is examined to determine if it exceeds a minimally acceptable return (sometimes called "the hurdle rate").

Hence, the IRR is defined as:

$$0 = \sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t} \quad (2)$$

where IRR is the internal rate of return (%), CF_t is the cash flow of the investment in time period t (€).

The advantage of IRR is that, unlike NPV, its percentage results allow projects of vastly different sizes to be easily compared. Using IRR as a criterion for the acceptance or the rejection of a project is very simple: if the project IRR is higher than the discount rate, the project is accepted, otherwise it should be rejected. The higher the IRR (or the more it surpasses the required project productivity given by the discount rate), the more profitable the project is.

Payback period: A payback calculation compares revenues with costs and determines the length of time required to recoup the initial investment. A simple payback period is often calculated without regard to the time value of money. This figure of merit is frequently used to analyse retrofit opportunities, offering incremental benefits and end-user applications.

Based on previous findings and projected estimations, the above basic project figures will be calculated, so that the viability of the (example) project will be fully checked and verified. In this context, the IDT developed will help to verify the viability of the project considered (i.e. the 3-feedstock example) and further be used for the economic viability validation of other projects based on similar principles and assumptions.

Table 10
Components of capital cost estimates.

Cost component	Usual range of costs	Cost factor most commonly used
Major equipment-item cost		
+Erection		
+Piping		
+Instruments		
+Electrical		
+Civil works		
+Buildings		
+Lagging		
Direct Plant Costs (DPC)		=**100%** DPC
Engineering, design, supervision	10–20% of DPC	15% DPC
Management overheads	5–20% DPC	10% DPC
Installed Plant Costs (IPC)		=**125%** DPC
Commissioning	1–10% IPC	5% IPC
Contingency	0–50% IPC	10% IPC
Contractor's fees	5–15% IPC	10% IPC
Interest during construction	7–15% IPC	10% IPC
Total Plant Cost (TPC)		=**135%** IPC =**169%** DPC

5.1. Total plant costs (TPC) and CAPEX

Capital cost figures for anaerobic digestion plants are not easily obtained. Not only are they varying extremely (based on the basic technology and the various add-ons, especially what concerns pretreatment modules of different input feedstocks), but also capital cost figures mean different things to plant owners and to equipment suppliers, depending on the limits and boundaries of the equipment and services offered.

In this study, all capital cost items have been incorporated in the so-called total plant cost (TPC or "turn-key" cost). As such, they include the costs of the basic equipment plus costs for erection, piping, instrumentation, electrical works, civil works, buildings, engineering, management, commissioning, contingency and interest during construction.

TPC has been used, so that realistic estimates of the total cost of constructing a working system can be calculated. It is important to recognize that capital costs can be quoted at various levels that include or exclude certain components of the TPC. These different levels are further indicated in Table 10.

The capital or investment cost represents the TPC, unless otherwise stated. However, special attention should be given in quotations from technology vendors to the relevant costs referred to. Adding to TPC the development costs (conceptual idea to maturity, costs of permits and pre-financing costs) and the contingency, the CAPEX for the entire investment is finally derived.

In the following section, the CAPEX for a model biogas plant (MBP) is further discussed, the MBP being a "generic" anaerobic biogas plant with an approximate treatment capacity of ≈20,000 tons/year and a specific CH_4 yield (see for comparison Table 3) of ≈330 Nm^3 CH_4/ton VS. This accounts (based on the mass- and energy balance calculation methodology already presented) to one ICE of 816 kW.

Based on real market values (taken from quotations from technology vendors/contractors) for the TPC of such a MBP and taking into account the development costs (≈7.5% of TPC) and the contingency (≈5% of TPC), the CAPEX for the MBP is derived in Table 11.

Taking into consideration the investment costs for AD plants that codigest liquid (pumpable) and other semi-solid waste and their respective analogy in the fuel mix (e.g. 77:23) the investment cost is approximated to 195–200€/ton [22].

The projections for the derivation of the CAPEX for the biogas plant based on the 3-feedstock example (in the following the actual biogas plant or ABP) are based on those for the MBP and are

Table 11
CAPEX of a model biogas plants (MBP) based on organic wastes.

CC	Capital cost (CC) item	€	€/ton[a]	€/kW[b]	%
1	Civils and infrastructure	430,000	22.64	527	11.36
2	Reception and pretreatment		0.00	0	0.00
	2.1 organic wastes only	19.26	448	9.66%	8.86
	2.2 energy crops (additional)[c]	10.53	245	5.28%	13.67
3	Digestors and ancillaries	540,000	28.43	662	14.26
4	Decanter	180,000	9.48	221	4.75
5	Biogas cleaning system	174,000	9.16	213	4.60
6	SCADA and switch boards	441,600	23.25	541	11.67
7	Other subsystems	185,000	9.74	227	4.89
8	Cogeneration unit	846,630	44.68	1040	22.42
	Total MBP cost (TPC)	**3,365,044**	**177**	**4124**	**88.89**
9	Project development (7.5% of TPC)	252,378	13.29	309	6.67
10	Contingency (5% of TPC)	168,252	8.86	206	4.44
	Total costs (CAPEX)	**3,785,674**	**199.30**	**4639**	**100.00**

[a] Per ton treated organic wastes.
[b] Per kW of installed power (for the MBP it is estimated that the rated power output is approx. 816 kW_e).
[c] Considered only for the energy crops.

Table 12
CAPEX of the actual biogas plants (ABP) based on the 3-feedstocks example.

CC	Capital cost (CC) item	€	€/ton	€/kW	%
1	Civils and infrastructure	721,474	16.03	136	8.26
2	Reception and pretreatment	0	0.00	0	0.00
	2.1 Organic wastes only	613,779	13.64	115	7.03
	2.2 Energy crops	335,569	7.46	63	3.84
3	Digestors and ancillaries	906,037	20.13	170	10.37
4	Decanter	302,012	6.71	57	3.46
5	Biogas cleaning system	291,945	6.49	55	3.34
6	SCADA and switch boards	740,937	16.47	139	8.48
7	Other subsystems	310,401	6.90	58	3.55
8	Cogeneration unit[a]	3,805,248	84.56	715	43.57
	Total ABP cost (TPC)	**8,027,403**	**178**	**1508**	**91.92**
9	Project development (7.5% of TPC)	423,452	9.41	80	4.85
10	Contingency (5% of TPC)	282,301	6.27	53	3.23
	Total Costs (CAPEX)	**8,733,156**	**194.07**	**1640**	**100.00**

[a] Per kW of installed power (for the ABP it is estimated that the rated power output is approx. 5324 kW).

Table 13
Operating cost items for the actual biogas plant (ABP).

Item	Operating cost category	Where discussed
1	Personnel (labour) costs and overheads	Section 5.2.1
2	Operation and maintenance (O&M) cost	Section 5.2.2
3	Consumables	Section 5.2.3
4	Utilities (electricity and heat)	Section 5.2.4
5	Liquid fertiliser disposal	Section 5.2.5
6	Feedstock cost	Section 5.2.6
7	Contingency	Section 5.2.7
8	Amortisation	Section 5.2.8

approximated by the "6/10 rule", according to which:

$$\left(\frac{\text{CAPEX for ABP}}{\text{CAPEX for MBP}}\right) = \left(\frac{\text{treatment capacity of ABP}}{\text{treatment cpacity of MBP}}\right)^{0.6} \quad (3)$$

The costs of the cogeneration unit (cost item 8) are similarly approximated by the "8/10" rule. The ABP has a liquid: semi-solid ratio of 88:12, but given the uncertainty associated with treatment of semi-solid wastes, it is assumed that this corresponds satisfactorily with the respective MBP input waste ratio (77:23).

Hence, based on the CAPEX derived for the MBP (which has been validated from quotations from technology vendors and contractors), the CAPEX for the biogas plant in question is further depicted and the results are presented in Table 12.

A significant difference is derived upon comparison of the specific costs for the MBP and the ABP (4639 compared to the 1640 €/kW for the MBP and the ABP, respectively). This is not only due to the effect of scale (the ABP is almost double than the MBP), but also to the fact that specific methane yield (CH_4) production in the latter case (ABP, ≈500 Nm^3 CH_4/ton VS) is much higher than that in the former one (MBP, ≈350 Nm^3 CH_4/ton VS), due to the presence of feedstocks such as energy crops and glycerol.

Table 14
Personnel costs in the ABP.

Personnel	No. of persons	Salary (€/month)	Benefits (€/month)	Total (€/year)
Project Manager	1	4500	1500	71,998
Engineers	1	3200	1067	51,199
Workers (for the O&M)	4	2300	767	147,196
Accountant	1	2500	833	39,999
Total	**7**			**310,392**

5.2. Operational costs and revenues

Once the capital costs of the actual biogas plant have been estimated, another important factor for the feasibility of the project, i.e. the ABP operating costs, has to be determined. The operating costs for a biogas-to-energy project may be categorized into the following items, as shown in Table 13.

The summation of all the above operating cost items yields the TOCs for the ABP under consideration, based on the 3-feedstock example. These cost items are calculated in the following paragraphs.

5.2.1. Item 1: Personnel costs and general costs (fixed cost)

The required plant personnel and the associated costs (including all benefits) are summarised in Table 14.

General costs are usually calculated as overheads of the personnel costs and are assumed to be 10% of such costs. In the case considered here, the annual overhead costs are calculated at **46,559**€/year.

5.2.2. Item 2: Operation and maintenance (O&M) costs (variable cost)

Annual maintenance costs (spare parts and external assistance) are assumed to be between 3.0% and 5.0% of the TPC. In general, the pretreatment of energy crops is expected to move these costs to the higher end and, hence, result in higher maintenance costs than the pretreatment of organic feedstocks alone.

In the following, the plant O&M annual costs are assumed to be 5% of TPC or 401,370€/year.

5.2.3. Item 3: Consumables (variable cost)

The major cost when considering the consumables for a biogas-to-energy plant are the costs for the chemicals (lime and active carbon, for the removal of odours and other noxious gases) required for treating gases leaving the plant, or additional feed (if required) for the start-up of the digester (microbes).

In the following, the ABP costs for consumables are assumed to be 2.5% of TPC or 200,685€/year.

5.2.4. Item 4: Utilities (variable cost)

The main utility requirement is power to run all the plant's auxiliary equipment (pumps, blowers, fans, feeding systems, separator, etc.). This cost item has already been accounted for, indirectly, since it has been calculated as a "loss" of efficiency, usually 15% of the gross power output, of the biomass plant (self-consumption, see Table 6) and, hence, as a "loss of revenue" through lower delivered electricity to the power Grid.

Other costs related to utilities include:

Table 15
Basic assumptions for the financing of the ABP.

Parameter	Unit	Value
CAPEX (see Table 12)	€	8,733,156
Own equity	%	25.0
Grants	%	30.0
Loan (L)	%	45.0
Interest rate (r)	%	6.0
Loan (debt) payback period (n)	years	10

- the cost of heating the digesters and preheating of other equipment (this is an "internal cost" since the waste heat from the cooling jackets of the ICEs can be utilised for this purpose).
- other costs, such as diesel costs necessary for plant start-ups.

Due to the self-consumption of electricity and heat, the annual utilities cost is considered to be negligible.

5.2.5. Item 5: Liquid fertiliser disposal (variable cost)

It is considered that the liquid fertiliser leaving the decanter separator (approx. 11,500 tons/year, see Table 9) will be used for irrigation purposes, especially for growth of energy crops. However, environmental compliance may result in further treatment of the liquid fertiliser in an evaporator or a membrane type reactor (MBR).

In this case, the operational costs for such treatment are estimated to ≈2.5% of TPC or 200,685€/year.

5.2.6. Item 6: Fuel cost (variable cost)

When considering "classical" organic wastes, their disposal in dedicated plants (such as the biogas plants) provides the plant operator with a certain benefit (negative "gate fees"). Thus, in this case the delivery and treatment of organic wastes constitutes a revenue for the ABP which is discussed below.

However, when considering energy crops, there is a positive gate fee/feedstock cost for the plant operator, Moreover, the feedstock cost consists of three different components, namely:

1. feedstock acquisition cost (type, location).
2. feedstock transportation cost, from the feedstock production site to ABP.
3. feedstock processing cost (communition, milling, storage on site, etc.).

The estimation of the feedstock cost is beyond the scope of this task. It is strongly recommended that prior to any business plan an exhaustive and thorough feedstock assessment is undertaken to determine available feedstocks type and their respective costs. As an approximation, for the 3-feedstock example considered, it is assumed that:

- the cost of wheat straw is ≈30€/ton (delivered to the plant) or (see Table 3) 300,000€/year, while,

Table 16
Summary of operating costs for the 3-feedstocks actual biogas plant (ABP).

Item[a]	Operational cost item	(€/year)	% of TOC
	Fixed operational cost (FOC)		
1A	Personnel Cost	310,392	18.84
1B	Overheads (general costs on personnel)	46,559	2.83
	Total FOC (I)	356,951	18.84
	Variable operational cost (VOC)		
2	Operation and maintenance (O&M)	401,370	24.37
3	Consumables and chemicals	200,685	12.18
5	Liquid fertiliser disposal	200,685	12.18
6	Feedstock costs (energy crops)	450,000	27.32
	Total VOC (II)	1,252,740	76.05
7	Contingency (of total VOC-I)	37,582	2.28
	Total VOC (VOC (I) + contigency)	1,290,322	78.33
	Total operating costs (TOC)	1,647,274	100.00

[a] According to Table 13.

- the cost of glycerol (a by-product of the biodiesel plants) is ≈10€/ton (delivered to the plant) or (see Table 3) 150,000€/year (this is highly volatile, however, depending on the economics of the entire biodiesel industry).

Thus, the total feedstock cost for the ABP amounts to 450,000€/year.

5.2.7. Item 7: Contingency (on variable costs)

Operating costs estimates are subject to various uncertainties, especially in regard to feedstock costs and availability (see below) and process uncertainties. In order to account for these uncertainties, a 3% overrun is assumed on the sum of all operating costs (including fuel costs except capital amortisation). In our case, this constitutes an annual "expense" equal to the sum of the above (i.e. 2–5) cost items, that is 37,582€/year.

5.2.8. Item 8: Capital amortisation (fixed cost)

The assumptions for the financing of the ABP are listed in Table 15.

The annuity (i.e. interest and depreciation for the capital investment/own equity), X, is given by Eq. (4):

$$X = L \times \frac{r(1+r)^n}{(1+r)^n - 1} \tag{4}$$

where X, annuity (€/year), L, borrowed capital/loan (million €), r, interest rate (%), n, loan payback period (years).

Given the figures listed in Table 15, the annuity for the considered ABP is calculated from (4) at 533,950€/year.

Based on the above, the TOCs for the ABP, based on the 3-feedstock example, are summarised in Table 16.

Finally, the yearly revenues from the operation of the ABP are summarised in Table 17.

Table 17
Yearly revenues from the operation of the ABP.

Revenues (new plant)	Unit	Values	Unit		€/year
Electricity sales[a]	MWh_e/year	31,676 × 80.14	€/MWh_e	=	2,538,546
Thermal energy sales[b]	MWh_{th}/year	0 × 0	€/MWh_{th}	=	0
Fiber fraction (compost) sales[c]	tons/year	7,558 × 10.00	€/ton	=	75,582
Gate fees	tons/year	20,000 × 10.00	€/ton	=	200,000
Total revenues					**2,814,128**

[a] Exports to the grid (see Table 6).
[b] No energy sales are considered (the ABP operates in the so-called stand-alone mode).
[c] Sales of compost.

Table 18
Summary of project investment, project financing and actual biogas plant (ABP) operation parameters and costs.

Investment (CAPEX)		
Civil works	8.26%	721,474 (€)
Electromechanical equipment	83.66%	7,305,929 (€)
Other expenses	8.08%	705,753 (€)
Total	**100.00%**	**8,733,156** (€)
Project financing		
Own capital	25.00%	2,183,289 (€)
Grants and subsidies	30.00%	2,619,947 (€)
Long-term loan	45.00%	3,929,920 (€)
Total	**100.00%**	**8,733,156** (€)
Loan assumptions		
Taxation coefficient	(%)	30.00
Interest	(%)	6.00
Loan payback period	(years)	10
Grace period	(years)	1
Actual biogas plant operation (all figures in €/year)		
Yearly income I (sales of electricity)		2,538,546
Yearly income II (gate fees)		200,000
Yearly income III (sales of compost)		75,582
Total yearly income		**2,814,128**
Yearly expenses (=TOC)		1,647,274
EBITDA (earnings before interest, tax, depreciation and amortisation)		1,166,854

Table 19
Financial evaluation of the proposed ABP project.

Discount rate	(%)	12.00
IRR own capital, 10 years	(%)	13.4
IRR own capital, 20 years	(%)	20.2
Own capital payback period	(years)	8.76
NPV (own capital), 10 years	(€)	2,312,568
NPV (own capital), 20 years	(€)	3,812,745

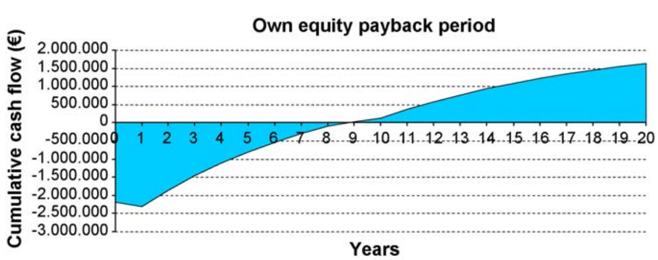


Fig. 3. Graphical representation of the payback period (own equity) for the 3-feedstocks actual biogas plant (ABP) project.

5.3. Derivation of the project's financial figures (viability of the project)

Once the main parameters of the ABP under consideration (based on the 3-feedstocks considered, see Table 3), the capital investment (CAPEX, see Table 12), the TOCs, (see Table 16) and the revenues (see Table 17) of the ABP, have been calculated and correlated with the plant's main operating parameters, the feasibility of the project can be further examined based on standard cash flow analysis.

The figures related to project investment (with regard to the CAPEX of the ABP), project financing (including loan assumptions) and ABP operation are summarised in Table 18.

Based on the above figures, the financial evaluation of the proposed project (i.e. the implementation and operation of an ABP based on the 3-feedstocks assumed) is given in Table 19.

The project's payback period on own capital is further shown graphically in Fig. 3.

6. Summary and conclusions

An IDT has been developed for the evaluation of the feasibility of biogas-to-electricity investments. The basic features of the IDT are the following:

1. IDT utilises existing data on a variety of biomass feedstocks, ranging from organic wastes to industrial by-products and energy crops. The IDT is able to consider the characteristics (the most important being the total and volatile solids and the potential evolution of CH_4) of a broad mixture of such organic wastes to be codigested in biogas plants based on anaerobic digestion.
2. Based on the input data, the IDT is given process performance assumptions and estimates as a first output, the mass and energy balances for the different streams of the biogas plant under study. In addition, the IDT calculates the electricity and the fiber fraction and liquid fertiliser outputs, performing standard calculations.
3. Taking into consideration:
   - the market prices for the end-products (electricity, heat and compost) and additional revenues.
   - the gate fees for a number of organic wastes (such as outputs of industrial activities).
   - the costs associated with the acquisition of biomass streams (energy crops).
   - the total investment cost (CAPEX).
   - the total operating costs on an annual basis, and,

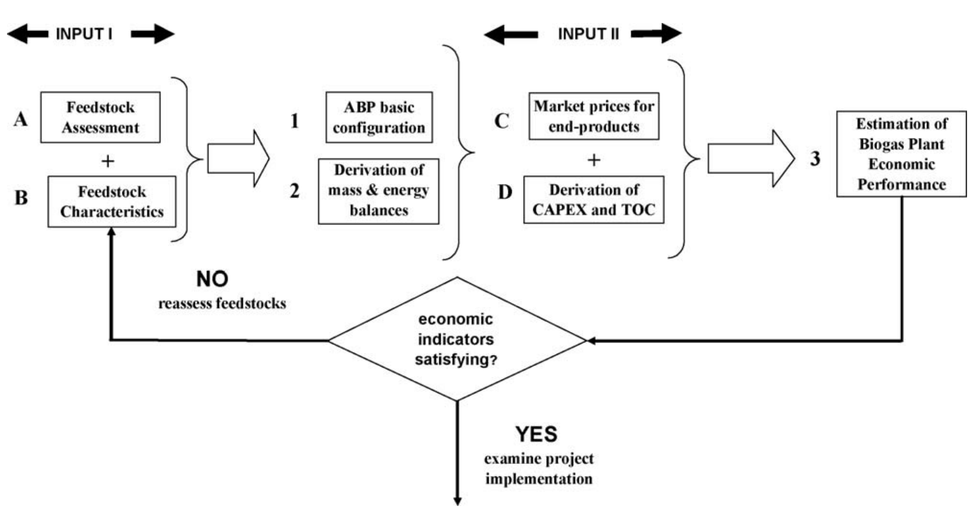


Fig. 4. Investment decision tool (IDT) key structure indicating input data and output streams.

- given financing parameters (such as the existing grants and subsidies and loan assumptions).

the IDT calculates the economic performance of the plant in terms of essential economic indicators such as the IRR, the NPV and the payback period of own equity using simple cash flow analysis.

Based on the outputs of the economic performance, the IDT examines whether the results are satisfying and iterates the entire procedure by simply reassessing different feedstocks input.

A diagram of the IDT key structure is schematically shown in Fig. 4.

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